

PERSPECTIVE

Intergovernmental Panel on Climate Change: Transparency and integrated assessment modeling

Jim Skea¹  | Priyadarshi Shukla²  | Alaa Al Khourdajie¹  | David McCollum³ 

¹Centre for Environmental Policy, Imperial College London, London, UK

²Ahmedabad University, Amrut Mody School of Management, Global Center for Environment and Energy, GICT Building, Central Campus, Ahmedabad, Gujarat, India

³Electric Power Research Institute, Palo Alto, CA, USA

Correspondence

Jim Skea, Centre for Environmental Policy, Imperial College London, Weeks Building, 16-18 Prince's Gardens, London SW7 1NE, UK.

Email: j.skea@imperial.ac.uk

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Abstract

Integrated assessment models (IAMs) connect trends in future socioeconomic and technological development with impacts on the environment, such as global climate change. They occupy a critical position at the global science-policy interface. IAMs and associated scenarios have come under intense scrutiny, with critiques addressing both methodological and substantive issues, such as land use, carbon dioxide removal and technology performance. Criticisms have also addressed the transparency of IAM methods and assumptions as well as the transparency of the Intergovernmental Panel on Climate Change (IPCC) assessment of IAMs. This paper, authored by the co-chairs of IPCC Working Group III and members of the Technical Support Unit, documents activities aiming to enhance the transparency of IAMs and their assessment. It includes a history of IPCC's approach to scenarios covering the formation of the Integrated Assessment Modeling Consortium (IAMC) in 2007 and the emergence of the approach by which IPCC facilitates the development of scenarios, but does not produce them itself. An IPCC Expert Meeting at the start of the current assessment cycle made transparency recommendations targeted at both the research community and IPCC. The community has taken steps to “open the black box” by moving toward open-source and web-publishing IAM documentation. IPCC has included an Annex to its next report focusing on scenarios and modeling methodologies. An open call for scenario data linked to the current IPCC report includes an expanded set of input and output variables. This paper ends with suggested criteria for measuring the success of these efforts to improve transparency.

This article is categorized under:

Integrated Assessment of Climate Change > Applications of Integrated Assessment to Climate Change
 Integrated Assessment of Climate Change > Integrated Assessment Modeling

KEYWORDS

integrated assessment, IPCC, modeling, scenarios, transparency

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1 | INTRODUCTION

Global integrated assessment models (IAMs) play a unique role in connecting assumptions regarding socioeconomic activity and technology with impacts on the global climate system (Weyant, 2017). They sit alongside other models with a national or sectoral focus (e.g., energy, land use) which provide more granular insights into climate change mitigation. Some IAMs have a decades long history having evolved from models with a more limited coverage, for example, energy systems. Modules covering land systems, the macroeconomy and climate emulation have been added over time. The characterization of socioeconomic systems and technology in IAMs is of necessity simplified. In this respect IAMs are not unique. All models used in the sciences and social sciences are abstractions of entire real-world systems (Giere, 2004).

There has been an expanding coverage of IAM modeling in successive assessment reports of the Intergovernmental Panel on Climate Change (IPCC) (van Beek et al., 2020). In the Sixth Assessment Cycle (AR6), the report of IPCC Working Group (WG) III, which focuses on mitigation, includes a chapter called *Mitigation Pathways Compatible with Long-Term Goals* that is heavily reliant on the IAM literature. This is one of 17 chapters which collectively cover current emission trends and drivers, mitigation at the sectoral level, cross-cutting issues such as policy and finance, and the links between mitigation and sustainable development.

The literature relevant to the *Mitigation Pathways* chapter includes some notable criticisms of IAMs, covering issues such as the treatment of uncertainty, intertemporal discounting, the characterization of technical change, land use and carbon dioxide (CO₂) removal. IAMs have played a prominent role in international climate policy debates relating to the limiting of global warming and net zero emissions, as well as the choice of mitigation strategies which may have large socioeconomic and environmental consequences. Their increasingly prominent role helps to explain the increasingly high level of scrutiny they have attracted in recent years.

The purpose of this paper is to document how both the IAM community and IPCC are working to enhance transparency and to suggest some criteria for judging the success of these efforts. The authors of this paper include the co-chairs and members of the Technical Support Unit (TSU) of IPCC. They are responsible for coordinating the production of the IPCC WG III report.

The IPCC assessment process is intended to address the treatment of substantive scientific issues such as those pertaining to IAMs, and these are not addressed in this paper. However, the literature also contains process-related criticisms concerning the transparency of IAMs and the related IPCC assessment processes (Robertson, 2021; Rosen, 2015). This paper sets out how both the IAM community and IPCC are working to enhance transparency. Although the paper of necessity focuses on process-based issues, we argue that there are important links between transparency and substantive scientific issues. Progress can be made on substantive issues only if debate is well-informed. Transparency about methods and assumptions is an absolute prerequisite in this respect. Transparency does not in itself guarantee scientific closure, but it facilitates debate and provides a clearer evidence base for policymakers.

The paper first looks at IPCC assessment processes and the treatment of scenarios (Section 2). It then considers different dimensions of transparency (Section 3). Section 4 summarizes recommendations regarding transparency made by an Expert Meeting held early in AR6. The first set of recommendations were for IPCC itself (Section 5); the second set were for the scientific communities whose work is assessed by IPCC (Section 6). Sections 5 and 6 also document actions taken in response to the recommendations. Section 7 concludes with a discussion of the criteria that might be applied to assess the success or otherwise of efforts to enhance transparency.

2 | IPCC ASSESSMENTS AND SCENARIO PROCESSES

The IPCC is mandated to provide regular assessments of the state of knowledge on the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. Its reports are formally accepted by member governments and the “summaries for policymakers” are approved line-by-line. It does not conduct or publish its own research.

IPCC has engaged actively with scenarios since its inception. Up to the Fourth Assessment report the IPCC developed its own scenarios. The SRES scenarios, named after the Special Report on Emissions Scenarios which documented them (Nakicenovic et al., 2000), were used in the Third (2001) and Fourth Assessments (2007). Four storylines were modeled to assess the uncertainties in socioeconomic drivers of future greenhouse gas (GHG) emissions.

Criticism of the approach to scenarios and models in IPCC reports is not new (Castles & Henderson, 2003; DeCanio, 2003; Schneider, 1997). Castles and Henderson (2003) for instance focused on the choice of market exchange rates (MERS) rather than purchasing power parities (PPPs) to bring national GDP data to a common basis. This specific debate subsided, but it prompted the IPCC to engage in an internal debate about its use of scenarios. An Expert Meeting held in 2005 (IPCC, 2005a) discussed three options for IPCC with respect to scenarios: (a) no specific role, other than assessing existing scenario literature; (b) organizing a process with the scientific community, driven by modelers, in developing new scenarios; and (c) developing new scenarios within IPCC. The Meeting recommended the second option on the grounds that credibility would be best assured by the scientific community with IPCC taking an advisory role. The case for IPCC involvement was based on ensuring continuity and consistency in terms of transparency of assumptions. The Panel subsequently endorsed the second option (IPCC, 2005b).

In 2007, the Integrated Assessment Modeling Consortium (IAMC) was established to lead the development of new scenarios (IAMC, 2021). The IPCC decided to organize the Fifth Assessment Cycle (AR5) around a set of scenarios—“representative concentration pathways” (RCPs)—whose starting point was GHG concentrations rather than socioeconomic drivers (Moss et al., 2008).

Late in AR5, but too late for the AR5 report itself (IPCC, 2014), five narrative-based shared socioeconomic pathways (SSPs) were developed based on the capacity of societies to mitigate and adapt to climate change. The SSPs can be combined with the RCPs in a two-dimensional space (O'Neill et al., 2014). The SSPs underpinned some of the scenarios assessed in the Special Report on Global Warming of 1.5°C (IPCC, 2018a), and are explicitly cited in the Special Report on Climate Change and Land (IPCC, 2019a) and in the approved scope of the WG III AR6 report (IPCC WG III, 2017).

Given their influential role with respect to global and national policy processes, the visibility of IAMs has increased markedly in recent years, as has the level of scrutiny from both inside and outside of the IAM research community. There has been an increasing number of published critiques since AR5. Those from within the IAM community tend to focus on improvements to the modelers' art; some from the outside offer more fundamental criticisms. Recent papers have addressed, *inter alia*: approaches to uncertainty (Pindyck, 2017); capturing discontinuities (Weyant, 2017); assumed technology costs and real world developments (Krey et al., 2019; van Sluisveld et al., 2018); reliance on large-scale CO₂ removal with implications for land use (Anderson & Peters, 2016; Gambhir et al., 2019; Larkin et al., 2018); economy-wide rebound effects from improved energy efficiency (Brockway et al., 2021); and lack of attention to the demand side (Pye et al., 2021). Another strand of literature in the social sciences addresses the potential power of IAMs to shape the policy debates which they are intended to inform (Longhurst & Chilvers, 2019; McLaren & Markusson, 2020). For example, it has been argued that the prominent role assigned to CO₂ removal technologies in many scenarios legitimizes their deployment and weakens the case for early mitigation action (Anderson & Peters, 2016).

Some papers explicitly address the transparency of IAM models and modeling activity, citing lack of documentation and peer review of models, and the cloaking of value-laden assumptions and output uncertainties (Robertson, 2021; Rosen, 2015). Wilson et al. (2017) argue that verifiability is an important criterion for assessing IAMs. Verifiability (“are model results repeatable or model structure accessible to 3rd parties”) can be evaluated only through documentation, checks and review since IAMs cannot be validated against real world outcomes (DeCarolus et al., 2012).

3 | WHAT DOES TRANSPARENCY MEAN?

IAMs are complex constructions based on scenario assumptions, technical input assumptions and theoretically underpinned model structures. They have different system boundaries in terms of natural, human, and technical systems (Krey, 2014). Given the complexity of IAMs, transparency has several dimensions. Understanding of basic aspects is essential for an appreciation of a model's capabilities and limitations; other aspects may require detailed technical understanding. While these considerations apply to all models, IAMs have been subject to a particularly high level of scrutiny given their prominent role in climate policy debates.

A key issue is transparency for whom. While technical detail matters to the modeling community, decision makers and model users may be more concerned about high-level model design, key technical assumptions, and critical modeling practices. Examples of key assumptions include population and income projections, social discount rates and the capital costs of specific technologies; an example of modeling strategy is the practice of aiming to hit a target level of warming by 2100 while constraining cumulative net CO₂ emissions over the 21st century. This generally results in an overshoot of the target temperature in mid-century.

3.1 | Model structure

This can cover: a model's modular structure (which sectors are covered and their linkages); whether it is partial equilibrium or general equilibrium, the latter linking climate mitigation with the broader macro economy (to what extent does it capture the interactions between multiple sectors); its theoretical underpinnings (does it optimize, or does it simulate agents' responses to economic signals); and its approach to foresight (do agents have prior knowledge of developments over the model's time horizon, or do they respond to economic signals over the life of investments) (Scrieciuc et al., 2013). This information is generally well-documented on publicly accessible websites.

3.2 | Input assumptions

IAMs require large arrays of input assumptions. Varying some may have little impact on results; others may make a big difference. Full transparency would require published documentation of all assumptions, but this is patchy in practice. Diagnostics and sensitivity analysis have been carried out to compare the responses of different IAMs to changes in key technology costs and carbon price (Barron & McJeon, 2015; Bosetti et al., 2015; Krey et al., 2019; Kriegler et al., 2015). IAMs are still subject to criticism for not being transparent about the technology input assumptions (Robertson, 2021; Rosen, 2015).

3.3 | Model equations

The basic equations used in most models tend to be well documented in public reports or on websites though this information may have been published in the more distant past for some of the older models.

3.4 | Model code

Actual model code, along with training materials that would enable a third party to run a model, is available in a few cases. This is consistent with the aims of the open-source movement to license computer software so that users can modify it according to their own needs (IEA-ETSAP, 2021; IIASA, 2021b; JGCRI, 2021; PIK, 2021).

3.5 | Modeling strategies

IAM teams have sought to produce scenarios consistent with indicators such as GHG concentrations or global warming levels. IAMs generate these outputs using climate emulators (e.g., MAGICC, 2021) taking emissions from the main IAM model as their input. As a proxy for climate ambition, IAMs have typically constrained cumulative net CO₂ emissions over the 21st century and subsequently categorized model runs according to the resulting GHG concentrations or warming levels. This approach interacts with assumptions about social discount rates to determine how models operate over multigenerational timescales. Lack of documentation of discount rates has come in for recent criticism (Anderson & Peters, 2016; Emmerling et al., 2019). These approaches are well understood by modelers, but they could be better communicated to model users. Bistline et al. (2021) argue in favor of “deep transparency” which entails “making structural assumptions explicit ... and explicitly communicating value-laden assumptions.”

4 | PREPARATIONS FOR THE IPCC 6TH ASSESSMENT CYCLE

An Expert Meeting on Mitigation, Sustainability and Climate Stabilization Scenarios was held at the start of the AR6 cycle (IPCC, 2017). This meeting built on the findings of an IPCC cross-Working Group Expert Meeting on Scenarios held at the end of AR5 in 2015 (IPCC, 2016). The 2017 meeting, involving modelers, non-modelers, and IPCC stakeholders, included the following objectives:

- To open the “black box” and explain what insights models/scenarios can provide, and their limitations;
- To link the top-down and the bottom-up by identifying indicators that are explicit or implicit in model reporting; and
- To develop recommendations for communicating scenarios effectively to policymakers.

The resulting recommendations were targeted at three different audiences: attendees at the subsequent Scoping Meeting for the AR6 Working Group Reports; the IPCC leadership in respect of the conduct of AR6; and research communities associated with scenarios and modeling. Recommendations relevant for transparency directed at the latter two audiences, and their follow-up, are discussed in Sections 5 and 6.

The 2017 scenarios meeting took place after the scoping of the Special Reports on Global Warming of 1.5°C (IPCC, 2018a), Climate Change and Land (IPCC, 2019a), and Oceans and Cryosphere in Changing Climate (IPCC, 2019b).

Following the scenarios meeting, the IAM community accelerated its efforts, using existing models to conduct research which could be cited in the Special Report on Global Warming of 1.5°C. A dozen modeling teams submitted more than 400 scenarios described in work accepted for publication by May 2018. The IAMC holds annual meetings and has Scientific Working Groups addressing Evaluation and Diagnostics (describing, documenting, and understanding the performance of IAMs) and Data Protocols and Management (focusing on the standardization of reporting formats).

5 | RECOMMENDATIONS FOR AND FOLLOW-UP FROM IPCC

5.1 | Recommendations for IPCC

Several of the IPCC-targeted recommendations of the 2017 Expert Meeting touched on transparency, directly or indirectly. These focus on the work of scientists involved in IPCC assessments. Steps taken to engage a wider range of stakeholders are described in Section 5.2. The recommendations included:

- Document the treatment of scenarios across all three IPCC Working Groups in a single location.
- Hold cross-working group discussions on best practices for presentation and communication of scenario ranges.
- Select authors with a wide range of expertise, and authors that can enhance integration across working groups.
- Establish a clearer distinction between “assessment” and “research,” and communicate this distinction to the authors.
- Establish a cross-chapter contact group within WG III on scenarios and modeling.

5.2 | Actions taken during AR6

The following steps have been taken to enhance the transparency of modeling and scenarios in the WG III AR6 report:

5.2.1 | Scope of the WG III AR6 report

The report will have an annex dedicated to scenarios and modeling methodologies (IPCC WG III, 2017). Chapter 3, *Mitigation pathways compatible with long-term goals*, the home chapter for IAM modeling, will consider “methods of assessment, including approaches to analysis of mitigation and development pathways.” In addition, the AR6 report divides the future into two timeframes. One chapter has a 2100 time horizon while another addresses mitigation and development pathways in the near- to mid-term. The latter chapter covers models other than those that might be classified as IAMs.

5.2.2 | Author selection

In making its selection of authors for Chapter 3, the WG III Bureau (IPCC, 2018b) followed the Expert Meeting recommendation to include authors with a wide range of expertise, including those outside the IAM community. These

included individuals who had been critical of IAMs in the published literature at the time they were selected, those with expertise in fields such as forestry, land use, and bioenergy where the credibility of IAMs has been questioned, and those with wide perspectives on socioeconomic development.

5.2.3 | Scenarios database

As with the WG III AR5 report (IPCC, 2014; 2021a) and the Special Report on Global Warming of 1.5°C (IPCC, 2018a), an open scenarios database will document the scenarios assessed in the AR6 report. Previous databases have been criticized for providing scant information on input assumptions going beyond high-level indicators such as population and economic activity (Robertson, 2021). In AR6, the call for scenarios (IIASA, 2021a) was extended to include a wider range of technical parameters, including the assumed capital and operating costs of individual technologies, and service demand levels (e.g., floorspace, passenger kilometers). Separate calls were issued for scenarios at the global level and those at the regional and national level.

5.2.4 | Data archival and curation

IPCC relaunched its Task Group on Data Support for Climate Change Assessments (TG-Data) in 2018 (IPCC, 2018c). TG-Data has developed guidelines aimed at enhancing the accessibility and transparency of data and scenarios underlying IPCC reports. The datasets behind figures, tables, and exhibits in the Summary for Policy Makers (SPM) and Technical Summary of WG III will be curated and archived. Full documentation, including data, metadata and information on the data and scripts used to produce these figures, tables and exhibits will be publicly available for up to 10 years.

5.2.5 | Engagement with a wider range of stakeholders

Scenarios assessed by IPCC are widely cited and used by governments, industry, the financial sector and NGOs. Transparency also means communicating modeling methods and assumptions to those who may not have the resource to read detailed technical documentation. During the first and second reviews of the WG III contribution to AR6, webinars have been held involving authors alongside industry, environmental NGOs, and governments with the aim of sharing insights and exchanging views on assessment topics including those addressed by IAMs.

6 | RECOMMENDATIONS FOR AND FOLLOW-UP FROM THE MODELING COMMUNITY

6.1 | Recommendations

The list of recommendations from the IPCC (2017) Expert Meeting directed at scenarios and modeling communities included:

- Enhance transparency by being more explicit about assumptions, trade-offs, and uncertainties in scenarios.
- Identify gaps in knowledge in IAMs.
- Establish a scenario database that includes relevant scenarios from a variety of sources.
- Enhance communication between different scenario modeling groups.

6.2 | Actions taken

6.2.1 | Documentation

Most IAMs are documented, with a varying degree of detail, on websites and/or in technical reports. Often this documentation does not extend to detailed lists of input assumptions. The IAMC has set up a Wiki platform (IAMC, 2021)

for documenting and evaluating models. The fuller documentation, which covers 15 models as of February 2021, includes a description of: scope and methods; policies tested; socioeconomic drivers; macroeconomic structure; detailed sectoral coverage and mapping; and emissions coverage. The remainder of the participating models have “reference cards” that list the main features, such as the sectors covered.

6.2.2 | Open-source models

Some modeling teams provide full access to their models via open-source code and training material for potential users. Examples include: GCAM (JGCRI, 2021); MESSAGE (IIASA, 2021b); REMIND (PIK, 2021); and TIMES (IEA-ETSAP, 2021). An open-source model is generally available alongside a full set of reference input assumptions. The ability of third parties to run models is an important contribution to the verifiability of models, as observed by Wilson et al. (2017). However, this opportunity is not for the casual user and models may take considerable effort to master: IIASA (2021b) notes that running the MESSAGE model “requires domain knowledge, understanding of certain research methods, and scientific computing skills.”

6.2.3 | Model intercomparison projects

The IAM community has made heavy use of model intercomparison projects (MIPs) where different models are run using harmonized scenario assumptions (Fragkos et al., 2021; Schaeffer et al., 2020; Wilson et al., 2017). Some model intercomparison initiatives have a long history. The Energy Modeling Forum (EMF) has provided a platform for ongoing MIP studies since 1976 (EMF, 2021a) including most recently the EMF 36 study that investigates carbon pricing mechanisms in the context of the Paris Agreement goals (EMF, 2021b). MIPs often focus on policy relevant questions, but can also involve diagnostic testing (e.g., using the same demographic and carbon price assumptions) to help understand structural uncertainties associated with representations of the same system in different models.

6.2.4 | Scientific papers

As observed by some critics (Rosen, 2015), published peer-reviewed papers based on IAMs do not include full lists of input assumptions. This is at least partly because the volume of assumptions for an IAM is unmanageable in the context of scientific publishing practices. Some papers have focused on specific input assumptions. For example, Krey et al. (2019) investigated technology representation and assumptions relating to power generation for 15 models using data from four MIPs. In practice, the publication of detailed assumptions on websites and in gray literature is a pragmatic response, and scientific papers based on IAMs undergo, and regularly pass, full peer review.

7 | MOVING FORWARD: EVALUATING TRANSPARENCY EFFORTS

The prominence of climate change in public debate has shone a spotlight on IAM modeling, drawing attention to the practices of the modeling community and applying pressure to improve transparency to a greater degree than for most other types of models.

Recent efforts aim to enhance transparency and to communicate models and scenarios to wider stakeholder groups. This can be challenging, because many of the modeling tools have evolved over years, or even decades, and a full understanding would depend on absorbing information published in a variety of formats (papers, technical reports, websites) over a length of time. Users of IAM outputs do not always have the capacity to engage in this time-consuming activity.

In addition, scientific publishing requires the submission of novel contributions leaving little scope for voluminous methodological material which represents incremental progress. The IAM community has successfully and consistently published in the top-ranked scientific journals, regularly subjecting their work to peer review from both modelers and non-modelers. This indicates that transparency standards are institutionally embedded in scientific publishing practices, and are not simply the result of obfuscation by specific interests. Furthermore, a practical challenge to

transparency is the prevalence of project-based support for large-scale modeling activity which can limit the capacity to develop and document models systematically.

We have documented a range of activities under way to enhance the transparency of IAM models and modeling activity. Many of these activities are work-in-progress. So how will we know how successful these have been? We suggest that by the scheduled end of IPCC AR6 the following broad criteria, which could usefully be filled out by identifying more specific metrics, might be relevant, for both IPCC and the IAM community. These would signify real progress toward the verifiability of results as identified by DeCarolis et al. (2012).

- The extent of published papers addressing methodology, model assumptions, and model diagnostics.
- Web-based documentation of model design, input assumptions, and diagnostics.
- The extent to which modeling teams have offered full sets of data (key inputs and outputs) to online scenario databases such as the AR6 database.
- The prevalence of open-source models and the accessibility of accompanied training material.
- Clear “explainers” for users of models in the decision-making world.
- The acceptance of methodological material in IPCC products by member governments.
- The degree to which policymakers demonstrate a grasp of the implications of key methodological choices. This could become apparent when policymakers interrogate researchers during the course of science-policy engagement exercises such as the current UNFCCC Structured Expert Dialogue (UNFCCC, 2020) which is addressing issues such as GHG emission pathway characteristics, temperature overshoot, the balance of mitigation action in the near- and long-term, remaining carbon budgets and the role of CO₂ removal.

The quest for transparency has, in the case of IAMs, been prompted by their critical position at the global science-policy interface. The IAM community and IPCC have grasped the issue and are taking active steps to improve transparency, to a degree that might not be demanded in other areas of modeling. This journey is not yet complete. We expect progress by the end of IPCC AR6 but do not doubt that further efforts may subsequently be demanded and required.

CONFLICT OF INTEREST

Jim Skea and Priyadarshi Shukla are Co-Chairs of IPCC Working III; Alaa Al Khourdajie and David McCollum are members of the Technical Support Unit.

AUTHOR CONTRIBUTIONS

Jim Skea: Conceptualization-Equal, Formal analysis-Equal, Writing-original draft-Equal. **Priyadarshi Shukla:** Conceptualization-Equal, Formal analysis-Equal, Writing-original draft-Equal. **Alaa Al Khourdajie:** Formal analysis-Equal, Writing-review & editing-Equal. **David McCollum:** Methodology-Supporting, Writing-review & editing-Equal.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Jim Skea  <https://orcid.org/0000-0003-1573-4763>

Priyadarshi Shukla  <https://orcid.org/0000-0002-7305-2907>

Alaa Al Khourdajie  <https://orcid.org/0000-0003-1376-7529>

David McCollum  <https://orcid.org/0000-0003-1293-0179>

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